Integrating Models, Measures, and Visualizations of Acoustic Backscatter

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LONG-TERM GOAL

The long-term goal of this program is to quantify, understand, and visualize acoustic backscatter from fish. Our strategy integrates numeric backscatter models with computer visualizations and compares model predictions to laboratory and field measurements.

OBJECTIVES

Objectives of this project include: modeling acoustic backscatter from individual and aggregations of fish; integrating fish anatomy, orientation, ontogeny, and behavior in predictions of acoustic backscatter; comparing acoustic technologies used to quantify fish distributions and abundance; and visualizing acoustic backscatter from individual and aggregations of fish.

APPROACH

Kirchhoff-ray mode backscatter models, based on digitized x-ray images of fish bodies and swimbladders, are used to predict species-specific backscatter amplitudes as a function of acoustic wavelength, fish length, and fish orientation (i.e aspect and roll). Model predictions of backscatter from individuals are also scaled to estimate population backscatter, abundance, and are compared to laboratory and *in situ* field measurements.

WORK COMPLETED

Methodology to estimate packing densities of fish schools was completed using: probability distribution functions (PDFs) of Namibian pilchard tilts and rolls, Kirchhoff-ray mode (KRM) predicted backscatter, and scanning sonar backscatter measurements of fish schools. PDFs of fish

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tilts and rolls were also used to predict effective target strengths of pilchard aggregations as a function of fish length.

Seven papers were published or are in press this year with an additional paper in review. One workshop and eleven presentations were made individually, jointly, or in collaboration with others at regional, national, and international meetings.

East Coast

Acoustic backscattering measurements of live alewife (*Alosa pseudoharengus*) were obtained in a large laboratory tank, in collaboration with Benjamin Reeder, Dr. Tim Stanton, and Dr. Dezhang Chu of the Woods Hole Oceanographic Institute. An individual alewife for each series of measurements was tethered and rotated in two planes of orientation (dorsal/ventral and lateral). Alewife were insonified using a broadband (40-100 kHz) chirp signal and bistatic scattering geometry (Fig. 1).

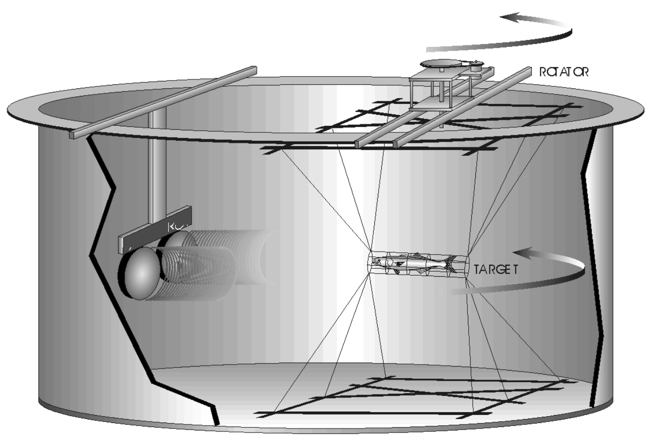

Figure 1. Experimental setup for broadband backscattering measurements. A source and a receiver transducer (bistatic backscattering geometry) were used to insonify a live alewife. Each alewife was tethered in a monofilament net bag, which was rotated at 1º increments using a computer controlled rotating mechanism. Each alewife was insonfied at lateral incidence (fish orientation as shown), and at dorsal/ventral incidence (fish laid on side).

Backscatter amplitudes for all angles of orientation (3-D scattering ambit) were modeled using a KRM model and digital images of the fish body and swimbladder morphometry.

West Coast

Backscatter KRM model predictions were completed for walleye pollock (*Theragra chalcogramma*), atka mackerel (*Pleurogrammus monopterygius*), striped bass (*Morone saxiltilus*), paddlefish (*Polydon spathula*), and chinook (*Oncorhynchus tshawytscha*) and sockeye (*Onchorhynchus nerka*)

salmon. Analyses comparing model predictions to backscatter measures for paddlefish are complete and ongoing for walleye pollock and capelin (*Mallotus villosus*).

Visualization of KRM backscatter ambits was enhanced to combine body and ambit visualizations in a single view, to include fish skin and radiograph texture mapping, and to provide an opacity option to view the swimbladder through the ambit or fish body. Backscatter ambit visualizations and other KRM research results were used to construct an interactive, fisheries acoustics website hosted at the University of Washington (http://www.acoustics.washington.edu).

RESULTS

Effective target strengths are calculated by weighting the predicted echo amplitude from KRM models by tilt and roll angle probabilities. The effect of tilt and roll is examined by comparing predicted target strengths from KRM models to those that incorporate tilt and roll PDF's in target strength tabulations. A total of 2000 random tilt and roll angles were used to tabulate tilt and roll PDF's for Namibian pilchard. Both distributions were centered on 90^o and had a spread of one (roll) or three (tilt) standard deviations. This represents an aggregation of fish swimming horizontally. Increasing the mean tilt angle above 90^o simulates fish migrating upward while mean angles less than 90^o simulate downward migration by fish. In Figure 2, the left panel plots the predicted (black line; 90^o tilt and 90^o roll) and effective target strength (green line; 70-110^o tilt and 80-100^o roll) of pilchard as a function of fish length at 38 kHz.

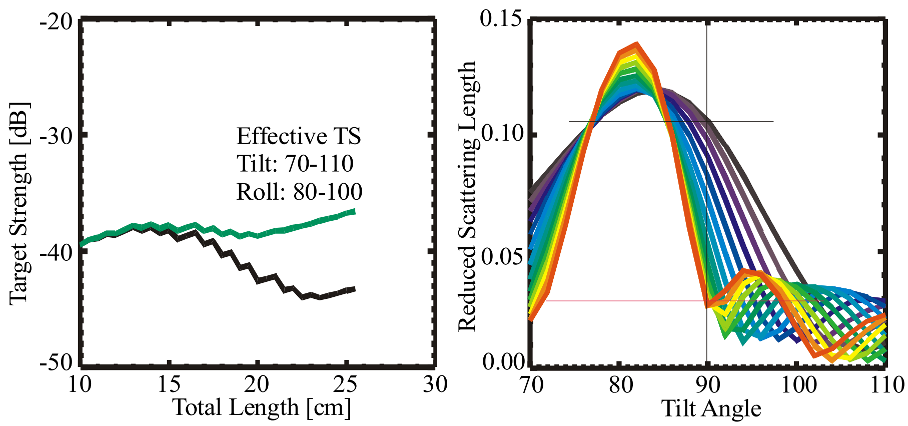

Figure 2. KRM predicted (black line, 90^o tilt, 90^o roll) and effective (green line, 70-110^o tilt, 80-100^o roll) target strength of pilchard as a function of fish length at 38 kHz. The right panel shows reduced scattering lengths as a function of tilt angle (70 – 110^o) for thirty-two pilchard ranging from 10 cm (black line) to 25 cm (red line) at 0.5 cm length intervals. The vertical line denotes 90^o. The horizontal black line intersects the 10 cm backscattering curve. The horizontal red line intersects the 25 cm backscattering curve.

The predicted and effective target strength curves are similar from 10 to 15 cm. For pilchard greater than 15 cm, effective target strengths increased over predicted KRM target strengths. Explanation for the divergence can be seen the in the right panel. Backscatter KRM models were constructed for 32 lengths from 10 to 25 cm at 0.5 cm increments (10 cm black curve - 25 cm red curve).

Backscatter curves between 10 to 15 cm (light blue) have roughly equal reduced scattering length values (i.e. echo amplitudes) above and below the value at 90^o (intersection of black vertical and horizontal lines). As fish get bigger (see red curve), a larger percentage of reduced scattering length values are larger than the value at 90^o (pink horizontal reference line). Higher backscatter amplitudes over a range of tilt angles results in larger predicted target strengths than at 90^o and larger effective target strengths. If we shift the mean tilt angle greater than 90^o then effective target strengths of fish less than approximately 22 cm are less than predicted target strengths at 90^o. When the mean effective target strength is less than 90^o, most effective target strengths are larger than those predicted at 90^o for fish lengths in this example.

East Coast

Broadband backscatter measurements of alewife showed frequency and orientation dependence (Figure 3). Maximum backscatter occurred at lateral incidence. Minimum backscatter occurred at tail- and head-on angles. Backscattering features (sharp increases and decreases in amplitude) occur in transition regions between head/tail and lateral incidences. Backscatter at lateral incidences can be 10-20 times greater than at head/tail insonification.

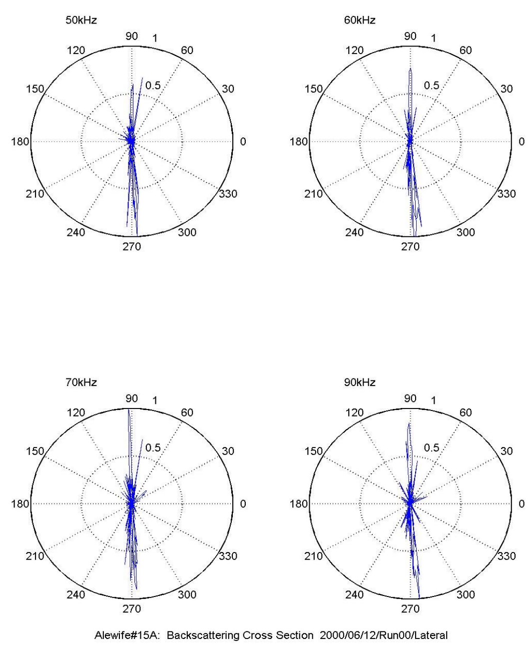

Figure 3. Backscatter amplitude as a function of angle of insonification and frequency. Backscatter amplitudes are plotted as the linear acoustic backscattering cross-section (σ_{bs}), and each polar plot is normalized to the maximum amplitude for each frequency. Zero degrees is "tail-on" insonification, 180^o is "head-on", and 90^o and 270^o are lateral incidence. The fish was laterally oriented in the net.

West Coast

Dorsal and lateral radiographs were used to investigate potential effects of growth, feeding, and reproductive cycle on backscatter amplitudes. At geometric scattering frequencies, the surface of the swimbladder closest to the incident wave front reflects most of the sound. Ratios of dorsal to lateral swimbladder areas among starved and gravid walleye pollock were always greater than unity. Dorsal swimbladder areas proportionately increased with fish length among starved (Fig. 4a) and fed (Fig. 4b) juvenile and adult fish. Contrary to prediction, dorsal swimbladder area of adult walleye pollock decreased when fish were fed (Fig. 4c). This result suggests that feeding distends the stomach laterally rather than compressing the swimbladder dorsally.

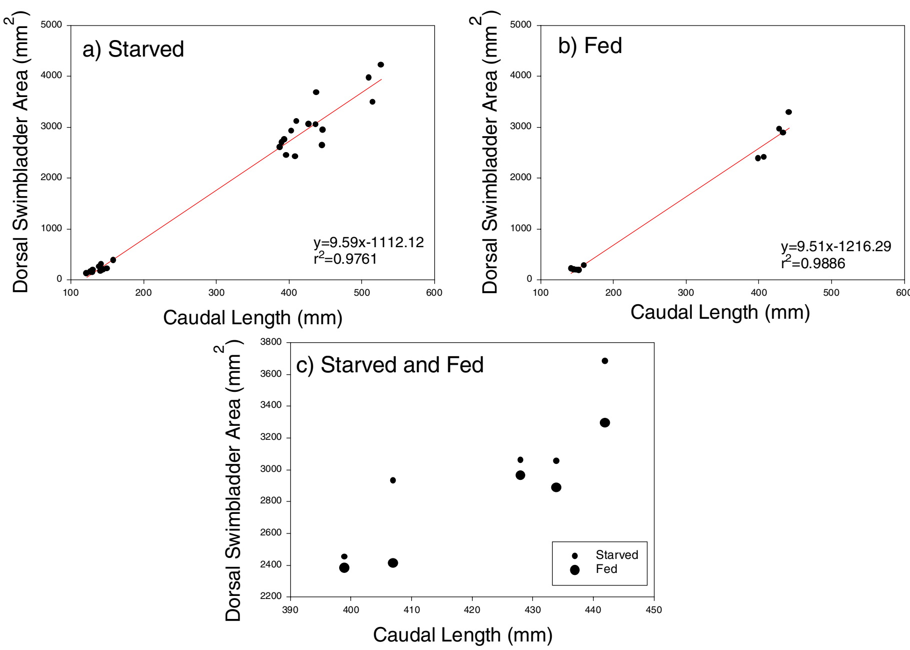

Figure 5. Walleye pollock dorsal swimbladder area as a function of caudal length for a) starved and b) fed fish. c) Comparison of dorsal swimbladder areas in five starved and fed walleye pollock.

IMPACT/APPLICATIONS

Incorporating behavior in target strength models should improve accuracy of population abundance and fish size estimates, facilitate acoustic monitoring of fish behavior, and contribute to the identification of acoustic targets. Broadband measurements of fish backscatter provide data for comparison to KRM model predictions and target discrimination using frequency-dependent scattering. Investigating the effects of fish ontogeny, physiology, and behavior on morphology quantifies the relative importance of biological factors influencing magnitude and variance of backscattered sound.

TRANSITIONS

Scientists at the Institute for Marine Research in Bergen, Norway are using KRM backscatter predictions to examine backscatter by fish schools and to customize software used to process sector-scanning sonar data. We have been approached to model backscatter from several species of freshwater and marine fish species including deep water Oreos and Orange Roughy.

RELATED PROJECTS

Walleye pollock and capelin target strength predictions are being compared to field data by researchers at the Alaska Fisheries Science Center in Seattle, Washington. Alewife backscatter predictions are being compared to laboratory measurements at the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts.

PUBLICATIONS

Demers, E., Brandt, S.B., Barry, K.L. and Jech, J.M. 2000. Spatially explicit models of growth rate potential: Linking estuarine fish production to the biological and physical environment. In *Estuarine Science: A Synthetic Approach to Research and Practice*. Edited by John Hobbie. Island Press, Washington DC, USA.

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Jech, J.M. and Horne, J.K. Effects of *in situ* target spatial distributions on acoustic density estimates. ICES Journal of marine Science (submitted).

PRESENTATIONS

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Horne, J.K. 2000. Quantifying distributions and dynamics of aquatic organisms. Invited lecture. University of Washington, School of Fisheries. Seattle, Washington.

Horne, J.K. 1999. Biological and physical influences on nekton distributions. Invited workshop. Department of Ecology and Evolution, University of California – Irvine, Irvine, California.

Horne, J.K. 1999. Use and abuse of acoustic backscatter models: Integrating theory and empiricism. Invited lecture. Department of Fisheries and Oceans, Institute Maurice-Lamontagne, Mont-Joli, Quebec.

Horne, J.K. and J.M. Jech. 2000. Incorporating behavior in target strength predictions of fish schools. ICES Fisheries Acoustics Science and Technology Working Group annual meeting. Haarlem, The Netherlands.

Jech, J.M. and J.K. Horne. 2000. Three-dimensional visualisation of fish morphometry and acoustic backscatter. ICES Fisheries Acoustics Science and Technology Working Group annual meeting. Haarlem, The Netherlands.

Jech, J.M. and J.K. Horne. 2000. Models and measurements of acoustic backscatter by individual and aggregations of fish. Invited lecture. Institute for Marine Research, Bergen Norway.

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